International Journal of Business and Management Study - IJBMS
Volume 3 : Issue 1 [ISSN 2372-3955]
Publication Date : 18 April, 2016

Impacts of Water Pricing Variability on Optimality Conditions of Water-Crop Productivity and Revenues Maximization

M. Ragy Darwish and Sami N. Khairallah

***Abstract*— One of the major daily challenging questions is how to manage the water resources around the globe? Currently, thirty-one countries face water stress and scarcity and over a billion people lack adequate access to clean drinking water. Crucial actions and serious measures should be taken in order to adjust or at least put back on track the deteriorating water resources conditions around the world. One way to enhance water usage is through the implementation of effective and efficient water pricing mechanisms that would lead to better water allocation policies and thus higher water use efficiency. The objective of this study is to assess the impact of applying different water pricing rates on the optimal cropping patterns and water productivity. Linear programming models were built and solved using LINDO software with a multitude of scenarios and sub-scenarios incorporating various constrains such as additional water provision and budget limitations. The study area includes the 700 irrigable dunums of the Agricultural Research and Education Center (AREC) of the American University of Beirut (AUB) in the Beqaa' valley of Lebanon. Sub-scenarios including additional water supply in dry months and budget constraints were developed to test for higher sensitivity responses. Sets replicating the cropping pattern applied in AREC returned inferior results (i.e., lower net profit and crop water productivity values) when compared with other set that includes newly suggested crops. The net profits and water productivity were further increased under scenarios with additional water supply (i.e., Supplementary Irrigation). Reducing the budget constraints by almost 50% had no impacts on the cropping patterns for either set of scenarios, implying that water availability is more of binding constraint in our case that cash availability. Scenarios with a wider set of crops resulted in higher water productivity and net profit levels. The study developed models and the results of this study could serve as effective guiding tools in helping the decision makers to take optimal choices with respect to the use of the available water resources, once relevant data are incorporated.**

Keywords— ***Linear Programming, Optimization, Optimal cropping pattern, Water productivity, Revenue maximization, Water use efficiency, Benefit cost ratio***

M. Ragy Darwish
Arts, Sciences and Technology University in Lebanon
Lebanon

Sami N. Khairallah
Mercy Corps International,
Beirut, Lebanon.

1. Introduction

One of the major modern-day challenges poses a question of utmost importance: how to manage the water resources around the globe? According to the Stockholm Water Symposium convened on August 2000, thirty-one countries currently face water stress and scarcity and over a billion people lack adequate access to clean drinking water. By consensus, the Symposium participants indicated that by the year 2025, as much as two-thirds of the world's population will be experiencing water shortages or absolute water scarcity. Since then several reports indicated that the problem will intensify further and faster than it was anticipated and the situation may came to be globally catastrophic unless serious measurements will be taken [3; 16; 15; 6]

Driven by globalization and its needs to constantly produce more, natural resources in general and water resources in particular are increasingly becoming degraded and polluted. Further adding to and magnifying the problem of water shortage. Suppliers and consumers are not aware or even concerned of the crucial need to use such a vital resource in a sustainable manner [16; 6]. Instead, water is being exploited in order to maximize immediate profits with no regard to the long-term consequences and impacts of such actions, on water availability and quality, in its various usages (i.e., municipal, industrial, agricultural, recreational, etc.).

The distinction between developing and industrialized countries in terms of water use awareness is becoming increasingly evident. In fact, the drastic difference in water management and water consumption between these countries is not likely to change any time soon. Water withdrawal in the majority of industrialized countries tends to decline and pressure put on water resources is diminishing whereas withdrawals in developing countries are constantly rising [2; 3]. The significant population boom in developing countries, especially in countries with severe water shortage is adding to the already existing stress on the water networks and could eventually lead to a humanitarian crisis.

With the continuous drastic grow in the world population, the escalating need for food and fiber production is inevitable. Consequently, the agricultural sector is now using more than 250 million hectares of irrigated land; nearly five times the amount that existed in the beginning of the twentieth century and the trend is expected to continue rising up [3; 16]. As a consequence, the major challenge is to find: first, an applicable solution to the phenomenon of the ever increasing water demand, due to the booming population growth (especially in developing countries), and second, a sustainable solution to the limited water resources that are constantly at risk due to inefficient usage if not the abuse of such resource, as well as the unfavorable climatic changes and the uprising of pollution and water degradation problems. All of which, if happened, my eventually trigger further an increase in food demand around the globe. This dilemma must be considered in any future plans for rational sustainable use of our water resources.

Lebanon benefits from relatively richer water resources than other countries in the region. However serious efforts will have to be made in order to conserve these resources that are subject to misuse and poor and inadequate management. Quba'a *et al.* [15] argued that, the introduction of an adequate water pricing scheme using the proper economic principles into the management of water resources will lead to an efficient allocation of water resources, specifically in irrigation water, and should be an integral part of a comprehensive and integrated plan or even strategy that should help in mitigating the water scarcity problems in Lebanon. Wastewater reuse especially in irrigation, after proper treatments of the effluent, is another approach that be considered within the comprehensive strategies [7; 6]. This study, however, will focus on the pricing mechanism as way to enhance water-crop productivity.

One of the main problems in water resources management in Lebanon is that current water charges fees are notably misrepresenting and undermining the true cost and value of water [15]. This phenomenon is clearly seen in the irrigation water [6]. Farmers are charged a price that by far is less than the actual costs of providing the water. As such farmers lack any incentive for adopting modern irrigation techniques. By charging the proper price that reflects the true water costs, farmers will most probably have higher motives to use water more efficiently and thus investing in improving their irrigation systems as well as planting crops that utilize water more efficiently. Adequate charging techniques would ultimately save significant volumes of water and would positively add to the pursued efforts aiming at improving water use efficiencies and enhancing water productivity in the agricultural sector, and consequently improving the allocation efficiency of almost two third of the available water in Lebanon, which represents the current water consumption by the agricultural sector in the country. Thus, one way of improving the irrigation efficiency and water-crop productivity index in Lebanon is to consider charging the farmers' price levels that will be close to almost cover the true economic cost of water use in agriculture.

Many studies utilized linear programming as an optimization technique to determine optimal solutions related to fresh water irrigation issues such as: maximizing net benefits, minimizing costs, determining optimal cropping pattern, determine the optimal pricing level, determine the daily operation decisions for irrigation water delivery, and water management strategies, and salinity control on farm or regional levels [5; 17; 8; 1; 4; 18; 12; 11]. However, limited studies have dealt with linear programming for optimization of wastewater reuse in irrigation. Linear dynamic programming models were also used to determine the cropping pattern that would remove all the nitrogen from secondary treated effluent and maximize revenues over variable costs [7; 6].

Study Objectives

The overall objective of this study is to assess the financial and economic impacts of different water pricing/charging levels on the cropping patterns, water-crop productivity levels, and optimal water allocation strategy and profit maximization for a selected set of crops. The objective will be achieved by developing extensive sets of optimization models using linear programming techniques with various scenarios and sub-scenarios to determine the optimal and most efficient way to use the water resources available for a certain set of crops and given a certain set of prices. In this study, the proposed prices are assumed to be collected as water fees from the water users.

II. Methods and Procedures

Study area and crop selection

The selected study area is within the premises of the Agricultural Research and Education Center (AREC) of the American University of Beirut (AUB) located in the Central Beqaa' valley. AREC represents a semi-arid climate with an altitude of 1000 M above sea level and the current existing cropping pattern consists of fruit trees, vegetables, cereals and other field crops (chickpeas, peas, lentil, etc.).

Water data was based on the "Master Plan for the Available Resources for Irrigation Management at AREC" a study that was conducted by Nimah and Jamous [13]. Six water sources are present at AREC with total net flow of approximately 580,931 m^3/ year. The quality of water from all wells was judged to be good and suitable for irrigation. For practicality purposes it was assumed that the total net available water from all the wells and are accessible and could be conveyed to all the land parcels that require irrigation.

As indicated in table 1 two sets of crops were considered in this study, current and newly suggested crops. The current crops are crops and fruit trees that were actually planted at AREC in 2007. For the newly suggested set of crops that are technically and economically feasible to be planted and grow at AREC. The new set of crops was suggested to provide more flexibility, bring in higher revenues and thus may improve the allocation efficiency and productivity per unit of water. All data related to the water requirements and water demand for the above crops were adopted from the Master Plan for the Available Resources for Irrigation Management at AREC [13].

Table 1: Current and Newly Suggested Crops Considered in the Current Study

Crops found in AREC in 2007	Newly suggested crops
Crops	Crops
Alfalfa	Cabbage
Barley*	Carrots
Barley/Vetch*	Cauliflower
Corn Field	Cucumber
Corn Sweet	Eggplant
Oat*	Garlic
Oat/Vetch*	Lettuce
Sorghum*	Melon
Vetch	Potato(early)
Fruit Trees	Potato (late)
Apple	Squash
Apricot	Tomato
Grape	Fruit Trees
Nectarine	Almond
Olive	Cherry
Peach*	
Pear	

*Crops that were dropped from the study because of their negative net return per dunum

Assumptions and Specification of the Study Scenarios:

In this current study a set of various price levels of irrigation water are used and incorporated in the study model. The values of the pricing lists were obtained and/or calculated from the findings and recommendations of several previous studies [7; 3; 15; 14; 6]. The set of considered prices represent local and international ones. The model's scenarios incorporated the following water pricing levels per cubic meter: $0.09, $0.18 and $0.36/M3. The first two represent local estimation prices, while the third represents an international figure that is commonly used under similar irrigation conditions.

An optimization model with different water pricing/charging levels scenarios is then developed, using Linear Programing Technique (**LP**), to determine the impact of the price variability on the optimal solution at the farm level and compare the monetary return to water consumption, as well as calculating the water-crop productivity index, for each scenario.

Four basic scenarios of the LP model are then developed and tested in order to achieve and fulfil the above stated study objectives. Moreover, a more extensive set of sub-scenarios, representing various sensitivity analysis aspects, are also solved to test for the optimality conditions variability and stability, via stimulating water scarcity conditions, varying the pricing and charging levels, the introduction of various monetary budget availability constraint, etc.

The first scenario **S1 (Status Quo scenario)** was set to reproduce the "exact" cropping pattern in terms of crops and allocated areas planted at AREC in 2007. **S1** included restrictions on land and crop allocation according to the actual pattern that was put into effect during that season. The objective of this scenario is to force the model to find the actual outcome of the current cropping pattern in terms of; profitability, water consumption levels, and crop-water productivity per M^3 of the produced crops at AREC.
The results are then used as a benchmark to compare and contrast them with outcomes of the other developed scenarios, so as to trace the changes in the direction and magnitude of profits and water productivity between the current plans versus the proposed ones in this study.

The second scenario **S2 (free model scenario)** included 23 different crops and orchard trees that could be planted in the Beqaa' Valley, nine of which were already planted at AREC in 2007. No land restrictions were added in that scenario, meaning that all or any set of crops can be planted all over the 700 irrigable dunums (du) available (A dunum equals to 1000 M^2), depending on the monthly water availability levels in 2007. The objective of this scenario is to test and compare the optimality conditions under the introduction of new crops and with no area restrictions per any given crop on the profitability levels, water-crop productivity levels and the associated cropping pattern.

Scenario **S3 (Supplementary Irrigation)**, is a replication of the status quo and free model scenarios but with supplementary irrigation is allowed and made available during months with higher water consummation levels that exceed the current available water supply. Prices of additional water were assumed to be the same as the suggested water price of each sub-scenario under study. Additional water supply was introduced during months of water exhaustion at three levels of application; low (25% additional water in specific month), medium (50% additional water in specific month) and high (75% additional water in specific month). The objective of this scenario is to reveal the impact of additional irrigation water during the needed months on the overall changes in profit maximization levels, cropping pattern stability and water-crop productivity values. I.e., this scenario is developed as an attempt to the answer the question of whether it is it economically and financially feasible to provide additional water during these months or not.

The fourth scenario **S4 (Monetary Budget Restrictions)**, aims at determining the effects of budget limitations on the outcome of the model under Free and Status Quo scenarios. This scenario allows determining the optimal cropping pattern depending on different budget availabilities. Different budget levels were selected based on the maximum cost of production per dunum as determined by Ghadban [10] to be $403 per du, or $282,100 for all 700 dunums in AREC (rounded to

$285,000 for practical purposes). As such, 15%, 30% and 50% of the $285,000 were imposed, representing low, medium and high budget availability levels, respectively, in this scenario.

Model Formulation

Given the above assumptions and specifications, the study model can be presented in the following form:

Objective Function

The study objective function is to maximize net profit of the produced crops over total costs and irrigation water costs, it can be written as follows:

$$\text{Max NR}= \sum_{i=1}^{n} (TRi - TCi - WCi) * Xi \qquad (1)$$

Where;

i represents the selected cropping activity, and it varies from 1 to 9 in **S1** (the Status Quo scenario) and from 1 to 23 in **S2** (the Free Scenario) that incorporates newly suggested crops.

NR is the total net return per dunum for crop *i*

TRi is the total revenue per dunum of crop *i*

TCi represents the total costs (fixed costs + variable costs + irrigation system cost, excluding water costs) incurred per dunum for crop *i*

WCi stands for the water charge per dunum for crop *i*

Xi stands for the number of dunums allocated for crop *i*

Constraints

The objective function is subject to the following constraints:

Total Cultivated Area Constraint (land Constraint)

The study area can fit a specific number of crops according to each crop's land occupation duration, depending on planting and harvesting date. However, at any given time, the overall planted surface cannot exceed the total available land area, therefore:

$$\sum_{j=1}^{12} \sum_{i=1}^{n} Xij \leq A \qquad (2)$$

For, i= cropping activity and j = month of the year, varying from 1 till 12

Xij is the area occupied by crop *i* during month *j* , and

A represents the total land available for planting

Total Water Availability Constraint

This constraint does not allow the projected water consumption per any given month to exceed the net water available from all sources at that specific month:

$$\sum_{j=1}^{12} \sum_{i=1}^{n} IRij \leq Qj \qquad (3)$$

IRij is the irrigation requirement per dunum (in m3/du) for crop *i in month j*

Q is the quantity or volume of water available in month *j*

Budget Availability Constraint

The budget availability constraint was integrated in scenario **S4** to limit the total amount of money available for the production of the selected crops and trees

$$\sum_{i=1}^{n} CPi \leq Bu \qquad (4)$$

CPi being the cost of production of crop *i* and *Bu* being the budget available for the whole project.

Non Negativity Constraint

This constraint assures that only positive results of the decision variables be considered in the model output, and is formulated as:

$$Xi \geq 0 \qquad (5)$$

III. Analysis and Results

The formulated study scenarios were run and solved using LINDO v.6.2. The impacts of the different water prices on the project's output was analyzed in terms of net profits, water volume consumed, cropping pattern variability and changes, crop-water productivity and other related factors. Comparisons between different scenarios with different characteristics were also made to reach a better understanding of what is/are the most important variable(s) that will significantly the enhance profitability and water productivity amongst the test ones.

Scenario (S1): Status Quo

The outcome of (**S1**) "exactly" mimics the cropping pattern as found at AREC in 2007. Tables 2 and 3 below summarize the main results obtained from this scenario at the three incorporated water pricing levels.

Table 2, represents the net profits above all costs (including the proposed water pricing level for each sub-scenario0, the change in the net return levels and the total volume of water consumed for the three subscenarios. As expected, Table 2 indicates that the net profit level declines as the water pricing increase for "the same imposed cropping pattern". Moreover, the total volume of water consumption is the same as the cropping pattern is the same, for the three subscenarios. As Table 2 indicates the highest net profits of US $34,727 were obtained at the price of $0.09/M^3, then it was decreased to $12,549, at the price of $0.36/M^3. To conclude, for the *status quo* scenario, the introduction of two additional water pricing values of $0.18, and $0.36, have resulted in a percentage reduction of 21% and, then 64%, in the value of the maximized net profit of as compared to the base price of $0.09.

Table 2: **S1** Net Returns and Water Volume Used

Sub Scenarios	Suggested Water Price ($/m^3)	Net Returns ($)	Total Volume of Water Used (m^3)
S11	$0.09	$34,727	82,081
S12	$0.18	$27,378	82,081

S13	$0.36	$12,549	82,081

Two additional water efficiencies indicators were also calculated from the obtained LP outputs, then analyzed and compared across the different subscenarios considered in this study. The two indicators are; water productivity of the produced crops and the benefit-cost ratio per unit of water used, for each subscenario. Water-Crop Productivity (WP) is defined and calculated in the context of this research as; the ratio of net profit to the total water volume consumed, for a given water scenario. As such the calculated value represents the average net profit of a given scenario for each M^3 of water consumed in a given scenario.

Table 3, displays the calculated water productivity values per M^3, at the three suggested and considered water pricing levels. The table indicates that each M^3 of irrigation water consumed for the three sub-scenario returns or "on average" adds $0.42, $0.33 and $0.15, respectively, to the total net profit values of the produced crops for each subsceanrio, at the three water price levels of $0.09/m3, $0.18/m3 and $0.36/m3, considered in this study. As noticed from the table, water productivity/M^3, as expected, declines as the price of one meter cube increases, for the "same" cropping pattern and water consumption, or *citrus paribus*.

Table 3: S1 Water Productivity and the BCR of Water Used

Sub Scenarios	Suggested Water Price ($/m^3)	Water Productivity ($/m^3)	BCR of water used ($)
S11	$0.09	$0.42	4.70
S12	$0.18	$0.33	1.85
S13	$0.36	$0.15	0.42

The benefit-cost ratio represents the net profit, above all costs, for each dollar spent on irrigation water used/consumed, in a given scenario. As seen from Table 3, the BCR per water volume consumed starts with 4.70 at water price of $0.09/m^3. The ratio indicates that a return of $4.7 of net profit is expected for each dollar spent on irrigation water, given the subscenario imposed conditions and restrictions. The ratio has dropped to $0.42 at water prices $0.36/m3.

Scenario (S2): Free Model

The second scenario, **S2**, includes the introduction of a set of potential new crops and fruit trees without any planting area restrictions for any given crop from the old and/or the new ones.

The main results of **S2** indicate that the water volume consumed at this scenario was doubled than **S1**, and remain the same at the different water pricing levels considered in the study (Table 4). In addition, the optimal cropping pattern was the same for all three sub-scenarios of **S2**. This means that although the overall project was incurring additional costs for irrigation water, it was still profitable to plant the same cropping pattern at each suggested price level. Furthermore, despite the fact that the "annual" available water volume estimated at approximately 580,930 m^3 the total volume of water consumed in **S2** could not exceed 192,643 m^3 since the monthly water volume available was exhausted for the months of May through September under the three pricing levels.

Table 4: **S2** Net Returns and Water Volume Used

Sub Scenarios	Suggested Water Price ($/m^3)	Net Returns ($)	Total Volume of Water Used (m^3)
S21	$0.09	$313,011	192,643
S22	$0.18	$295,476	192,643
S23	$0.36	$260,948	192,644

Table 5 displays the calculated Water productivity and the BCR values for S2 three subscenarios. The water productivity values vary from, $1.35, $1.53 and $1.62 /M^3, as from the table. The BCR outcome for the free model scenarios peaks at 18.05 for $0.09/m^3 water price (which implies that each dollar spent on water, returns on average $18.05 dollar in terms of profits), then 8.52 for the price of $0.18/m^3 and declines further to 3.76 for $0.36/m3 prices.

Given the results shown in Table 4, a 100% increase in water price per m^3- assuming a base water price of $0.09/m3- would only decrease the objective function value by 6%. And even when prices are doubled from $0.18 to $0.36/m3 the net profits decreased only by 17%. Such results could serve as incentives as a motive for establishing new water pricing policies that would bring higher returns to local water authorities, while reducing the farmer's revenues by an acceptable range, yet insures high water use efficiencies. Such additional returns to the water authorities should then be used to further enhance the efficiency of the irrigation delivery system (conveyance and distribution efficiencies) which ultimately will reduce wastes and conserve water.

Table 5: **S2** Water Productivity and BCR of Water Used

Sub Scenarios	Suggested Water Price ($/m^3)	Total Water Cost ($)	Water Productivity ($/m3)	BCR of water used ($)
S21	$0.09	$17,338	$1.62	18.05
S22	$0.18	$34,676	$1.53	8.52
S23	$0.36	$69,352	$1.35	3.76

Comparison between Status Quo (S1) and Free Model (S2)

Given the results of the two main scenarios **S1** and **S2**, Table 6 display the crops planted at AREC in 2007 (**S1**), versus the crops selected in the free model (**S2**). As seen in the table, it is obvious that the 2007 plantations found in AREC were far from being the best plantations in terms of profit making and water usage efficiencies, as well as the BCR of the consumed water volume. Instead, if AREC's management objectives were to increase their revenues while optimizing water usage efficiencies, the management should shift from producing the 9 crops (the same cropping pattern still in tell 2014) that are currently produce to only 6 crops that are selected in the S2. As table 7 indicates only 4 out of the current planted crops, namely; Apple, apricot, Grapes and Pears, should remain in the production plan with the addition to other two newly crops from the introduced list, namely, Lettuce and Cherry. i.e, with respect to the cropping pattern and given the objectives stated above in terms of revenues and water efficiencies, only 6 crops should be produced, with retaining of 4 out of the current and introducing additional new two.

Table 6: Actual Cropping Pattern Produced in 2007 at AREC (**S1**) Vs. Optimally Suggested Cropping Pattern Including Newly Introduced Crops (**S2**)

S1 (Status Quo)		S2 (Free Model)	
Plantation	Area Planted (du)	Plantation	Area Planted (du)
Alfalfa	28.00	Lettuce	388.24
Corn Field	59.35	Cherry	82.14
Corn Sweet	15.00	Apple	103.22
Apple	1.60	Apricot	20.47
Apricot	0.40	Grape	91.58
Grape	1.20	Pear	14.34
Nectarine	0.35		
Olive	2.34		
Pear	0.68		

The net returns generated from shifting the plans from S1 to S2, at water prices of $0.09, $0.18 and $0.36/m3, respectively, will result in an expected increase in the net returns of the produced crops by almost 800%, 1,000% and 2,000% for S2 as compared to the subscenarios of S1. Table 7 below represents the comparison between the net return values of S1 and S2.

Table 7: Comparison of the Net Profit Values for S1 and S2 three subscenarios (US$)

Sub Scenarios	Objective Function Values (US $)	% change
S11	$34,727	
S21	$313,011	801
S12	$27,378	
S22	$295,476	979
S13	$12,549	
S23	$260,948	1979

Moreover another remarkable finding is the different impact of the water price increase on the objective function value between Scenario S1 and S2: As seen in Tables 2 and 4, moving from $0.09 to $0.18/m3 in S1 produced a 21% decrease in the objective function value of S1 as compared to only 6% in S2. And even at higher levels, moving from $0.18 to $0.36/m3 diminished the Status Quo scenario's net revenues by 64% as compared to only 17% in the Free Model. As such, it can be argued that the impact of increase in water pricing levels will be higher in terms reducing the net returns in the presence of S1 crops as compared to S2. Once more, reiterating the significance of moving from S1 to S2, if overall higher profitability at higher water pricing levels is to be achieved.

Table 8, represents a comparison between the calculated water productivity for S1 and S2. The values in the table clearly indicate that the water productivity per m^3 for all S2 subscenarios exceeded by far the levels found in S1 subscenarios. At $0.09/m3, one meter cube of water returned $1.62 above production costs as compared to only $0.42 in S11, which represents almost a 290% increase in this value. This percentage difference escalates as the price of water increases to reach 365% and 800%, when we compare the values at the two addition price subscenarios of $ .18 and $ .36/m^3.

Table 8: Comparison of Water Productivity and BCR for S1 and S2 Three Subscenarios

Sub Scenario	Suggested Water Pricing Levels ($/M3)	Water Productivity ($/M3)	% change
S11	$0.09	$0.42	
S21	$0.09	$1.62	286
S12	$0.18	$0.33	
S22	$0.18	$1.53	364
S13	0.36	0.15	
S23	0.36	$1.35	800

The BCR of water costs to the total net revenues of the consumed water volume for S1 and S2 are calculated and compared in Table 9. As seen from the table, the BCR in the three subscenarios of S2 are at least three times greater than their values in the S1 subscenarios. In Table 9, a comparison of the BCR values for both S1 and S2 subscenarios, are displayed. The significant levels and magnitudes of the values obtain under each scenario as well as the significant percentage differences between the two scenarios are quite clear. The BCR ratio varies between 280% for the lowest water price ($0.09/M3) to peak to almost795 in the highest one. , which left no space for wording comments.

Table 9: Comparison of Water Productivity and BCR for S1 and S2 Three Subscenarios

Sub Scenario	Suggested Water Pricing Levels ($/M3)	BCR of Water consumption ($)	% change
S11	$0.09	4.7	
S21	$0.09	18.05	284
S12	$0.18	1.85	
S22	$0.18	8.52	361
S13	0.36	0.42	
S23	0.36	3.76	795

The compared values of Tables 8 and 9 indicate that as the water price level increases WP and BCR decrease, however, the proportional decrease in these values in S2 is in much less in magnitudes and percentages as compared to the same water pricing level of S1. That in turn suggests that with the optimal cropping pattern there is a quite space not only for higher revenues than the current status quo but also a room for applying a fair, adequate and efficient water pricing policies, that will lead to the benefits of both party the supplier (water authorities) and the consumers (farmers0, and to another third party which is the country/nation at large.

Sensitivity Analysis: S3 (supplementary Irrigation) and S4 (Budgets variation)

S3 is developed to test for the impacts of providing additional monthly water on the objective function values, the variability of cropping pattern, and water productivity values. In this scenario it was assumed that additional water could be provided during months with exhausted water reserves. Also supplementary irrigation volumes were introduced at additional 25% of the current monthly available water, and then increased to 50% and 75%, respectively.

In the case of the status quo (S1), the month of July is the only month with exhausted irrigation water in status quo model. Recalling that S1 has a fixed cropping pattern, therefore, allowing for additional water in exhausted month has no affect the cropping pattern and consequently on the net return and water productivity levels, i .e, the same results as introduced above were obtained. Therefore, additional supply of water is not recommended under status quo model unless a different cropping pattern is put into effect.

As for the free model (S2), the months of May through September were exhausted in terms of water availability. Allowing for supplementary irrigation at the three above mentioned levels (25%, 50% and then 75%), have resulted in cropping changes, and consequently in the net return values as well as the water productivity. The highest net returns have increased by almost 43%, 40% and 33%, respectively, under water price levels $0.09, $0.18 and $0.36, at a 75% increase in the supplemental water application. Less net return are achieved at the other two supplementary irrigation levels of 25% and 50%.

The results obtained in this scenario suggest that supplementary supply of water once provided and applied adequately, could bring higher returns to the farmers and yield better water productivity thus leading to further increase in the optimal usage of that valuable resource.

S4 (financial budget restriction) is introduced to test for the solutions stability under such conditions. For the status quo scenarios (S1), the cropping pattern adopted by the AREC management in 2007, returned the same profits and did not consume all the budget available for the three subscenarios (water pricing levels); consequently high budget restriction, i.e., up to 50% reduction, did not alter the cropping pattern that was produced.

Under Free Model subscenarios (S2), the same results were obtained. The budget restriction has no effect on the cropping pattern plan and thus the same values of the three subscenarios of S2 were obtained, even under 50% budget reduction.
The results obtained under S3 and S4 indicate that water availability is a more binding constraint than financial resources, given the current proportional availability levels of both resources that are considered in this study.

VI. Conclusions

Given the models' assumptions and specifications considered for the four scenarios, the following conclusion can be drawn :
The Status Quo scenario (**S1**) replicating the cropping pattern plan adopted at AREC, since 2007 till present, produces relatively low profits than its potential and has not optimally utilize the water resources available on the site. Much higher water productivities will be achieved by adopting an alternative (S2) plan which entails a more efficient use of water by introducing additional newly suggested crops to some of the current existing ones.

Moving from S1 to S2 Cropping plan, results in increasing the net profits by almost 800%, 1,000% and 2,000% at three water pricing levels of $\$0.09/m^3$, $\$0.18/m^3$ and $\$0.36/m^3$ considered in this study. As the water price level increase the net profit decrease as expected for both S1 and S2, however, the net impact of reduction was by far less in S2 than in S1, indicating that the farmer under the highest water price level in S2 cropping plan are still even better off in terms of profit making as compared to the net profit of S1 even at the lowest price level. That in turn suggests that farmers will be able to bear higher irrigation water price in S2 and still be able to make higher net profit than they are currently realize, while the water authority will be able to enjoy higher revenues with the additional increase in water fees (suggested price) and thus enabling them to enhance and improve their services' quality to the end users, i.e., the farmers.

The Water productivities, defined as the average net profit/m^3 of water, is calculated $\$0.42/m^3$ for the proposed $\$0.09/m^3$ in

S1, while it reaches $1.53/m^3 at the highest proposed price of water of $0.36/m^3 further reiterating the above stated conclusion. The same can be urged for the BCR of the water volume consumed in each scenario and its subscenarios.

From the above it can be stated that, water pricing strategy will be very rigid under the current cropping pattern at AREC, which pretty much represents the current situation in the |Bekaa Valley area, the main agricultural region in Lebanon. Pricing flexibility is at minimum and any attempts to increase the irrigation water prices will severely heart farmers and deeming there plans almost a failure. However, moving to the cropping plan proposed in S2, increase the water efficiency and profitability and even with increase in the prices, the reduction in net profit is by far less than the proportion increase water prices allowing farmers and water use authorities to enjoy additional revenues despite the increase in water pricing.

Currently, and under S1 only 14% of the total annual available water is consumed and even with S2 cropping pattern that almost doubled the water consumption, only 33% of this amount is used. The reason is mainly due to the water limitation in the month of May to September, as such pump the water and store it now, then use it later, can be a very good strategy. Such strategy will enhance the total water usage as well as further increasing profits and water productivity as suggested by the S3 (Supplementary Irrigation) scenario.

References

[1] Afshar, A. and Marino, M. A. 1989, Optimization Models for Wastewater Reuse in Irrigation, Journal of Irrigation and Drainage Engineering, ASCE, 115(2), pp. 185-202.

[2] Alcamo, J., Henrichs, T., and Rosch, T. 2000, "World water in 2025, Global modeling and scenario analysis for the World Commission on water for the 21st century." Kassel World Water Series- Report No 2

[3] Barlow, Maude. 2001,"Water as Commodity - The Wrong Prescription." Council of Canadians.

[4] Boman, B. J. and Hill, R. W. 1989, LP Operation Model for On-Demand Canal Systems, Journal of Irrigation and Drainage Engineering, ASCE, 115(4), pp. 687-700.

[5] Bowen, R. L. and Young, R. A. 1985, Financial and Economic Irrigation Net Benefit Functions for Egypt's Northern Delta, Water Resources Research, 21(9), pp. 1329-1335.

[6] Darwish M. Ragy, M. Sharara, M. Sidahmed and M. Haidar. 2007, "The Impact of a Storage Facility on Optimality Conditions of Wastewater Reuse in Land Application: A Case Study in Lebanon". Journal of Resources, Conservation and Recycling. Elsevier 51: 175-189

[7] Darwish, M. Ragy, F. El-Awar, M. Sharara and B. Hamdar. 1999, "Economic-Environmental Approach for Optimum Wastewater Utilization in Irrigation: A Case Study in Lebanon". Applied Engineering in Agriculture, ASAE, USA. 15 (1): 41-48

[8] Dinar, A. and Yaron, D., 1986, Treatment Optimization of Municipal Wastewater and Reuse for Regional Irrigation, Water Resources Research, 22(3), pp. 331-338.

[9] Eckert, J. B., and Wang, E., 1993, Effects of Irrigation Water Supply Variations on Limited Resources Farming in Conejos County, Colorado, Water Resources Research, 29(2), pp. 229-235

[10] Ghadban, E., 2007. "A modified sustainable model (idea) to compare organic and conventional agricultural systems in the Bekaa plain of Lebanon". MSc Thesis. Department of Plant Sciences, Faculty of Agricultural and Food Sciences, American University of Beirut, Beirut, Lebanon.

[11] Howitt, R.E. 2005, "Agricultural and Environmental Policy Models: Calibration, Estimation and Optimization." Unpublished Book, downloadable pdf draft; available from http://www.agecon.ucdavis.edu/; Internet; accessed 20 October,

[12] Mteirek, R. 1997, Irrigation Supply System Design for Optimal Cropping Pattern. Unpublished Master of Science thesis, American University of Beirut, Lebanon.

[13] Nima, M.N. and Jamous, C.A. 2007. "Master Plan for the Available Water Resources for Irrigation Management at AREC". Department of Agricultural Sciences, Faculty of Agricultural and Food Sciences, American University of Beirut, Beirut, Lebanon.

[14] Nimah Musa N., S. N. Moukarzel, M. R. Darwish, N. Farajalla and I. Bashour. 2006,"Water Productivity a Basic Tool for Sustainable Irrigation". Wessex Institute of Technology: pp 127-136.

[15] Quba'a, R, El-Fadel, M. and M.R. Darwish. 2002, "Water pricing for multi-sectoral allocation: a case study." *Water Resources Development* 18, 4:523-544.

[16] Rosegrant, Mark, Ximin Cai, and Sarah Cline. 2002. "World Water and Food to 2025: Dealing with Scarcity". International Food Policy Research Institute

[17] Tyagi, N. K. 1986, Optimal Water Management Strategies for Salinity Control, Journal of Irrigation and Drainage Engineering, 112(2), pp. 81-97.

[18] Zhenmin, Z. 1995, Optimization of Water Allocation in Canal Systems of Chengai Irrigation Area, Technical Sessions about Irrigation Water Delivery Models, FAO. 10 pages.

M. Ragy Darwish is Professor of Resources and Environmental Economics and the Research Coordinator in the Faculty of Business Administration at the Arts, Sciences and Technology University in Lebanon (AUL)

Sami N Khairallah is a Economic Development Specialist and the Operations Director at Mercy Corps International, Beirut, Lebanon.